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Bodily symmetry increases across human childhood

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Abstract

Background: Although bodily symmetry is widely used in studies of fitness and individual differences, little is known about how symmetry changes across development, especially in childhood.

Aims: To test how, if at all, bodily symmetry changes across childhood.

Study Design: We measured bodily symmetry via digital images of the hands. Participants provided information on their age. We ran polynomial regression models testing for associations between age and symmetry.

Subjects: 887 children attending a public science event aged between 4 and 15 years old.

Outcome Measures: Mean asymmetry for the eight traits (an average of the asymmetry scores for the lengths and widths of digits 2 to 5).

Results: Symmetry increases in childhood and we found that this period of development is best described by a nonlinear function.

Conclusion: Symmetry may be under active control, increasing with time as the organism approaches an optimal state, prior to a subsequent decline in symmetry during senescence. The causes and consequences of this contrasting pattern of developmental improvement in symmetry and reversal in old age should be studied in more detail.

Keywords: Symmetry, ageing, development

Introduction

Measures of symmetry – the degree to which an organism can equalise growth across species-typical symmetrical structures (1) — are commonly used for investigating canalization (2) and the effects of stress on development. A recent meta-analysis examining nearly 100 studies has identified a robust association between low symmetry and poorer health, adverse foetal outcomes and adverse hormonal effects (3). To the extent that lack of symmetry reflects an accumulation of errors and stress on the body, it is expected to increase with time. However, symmetry has been little studied in early development. In the one human study of which we are aware that measured symmetry data across childhood, symmetry increased rather than decreased with age (4). Symmetry may therefore index an active developmental process, improving with time as the organism matures. The study of symmetry in childhood may, therefore, shed light on the origins of symmetry, and of the traits with which it is correlated such as intelligence (5-7). It may also aid understanding of late-life processes of physical and cognitive decline (8). Animal research has shown that in swordfish the point at which an organism begins to shift resources from growth to maintaining symmetry varies according to genotype (9). It is possible to be growth-optimized and asymmetrical, or symmetrical but not growth-optimized. This suggests organisms may de-prioritize symmetry during periods where growth is of high priority – such as human childhood. For this reason, we undertook a study of bodily symmetry in childhood in two substantial samples.

If environmental impacts accumulate on the body from birth, then symmetry would be expected to decrease monotonically across the lifecourse. It might increase more rapidly late in life as vulnerability to insults increases, as reflected in higher risk of mortality. Symmetry might also show a steep slope early in life when vulnerability and mortality risks are also elevated above adult levels (10).

Alternatively, if active developmental processes are present which work to increase phenotypic quality (and increase symmetry) during maturation (11), then symmetry might decrease to some minimum level, perhaps early in adulthood, prior to increasing thereafter as stress is accumulated. This pattern is seen, for instance, in cognition, with fluid-type cognitive abilities increasing into early adolescence and declining later in life (12). Investigating age-associated changes in symmetry may therefore inform theories of the evolutionary implications of symmetry for bodily structure and function, and behaviour across the life course.

One study has reported on changes in symmetry during childhood (4). These authors investigated 680 participants aged 2–18 years. They identified a significant cubic effect of age (p = .01) on symmetry such that symmetry increased from age 2 until approximately age 11 followed by a brief loss of symmetry during the growth spurt from age 11 through age 15, and a return to increasing symmetry from age 15 until at least age 18 (the oldest age studied). Our own work suggests that this increase in symmetry reverses some time after this, with larger losses of symmetry late in life (8).

If replicated, the finding that bodily symmetry does not merely decline with ageing, but shows periods of systematic increase with maturation has significant implications. It suggests that changes in symmetry reflect not only cumulative stress, but that there are active processes which reduce the causes of symmetry as the organism approaches important life-stages such as the end of childhood, or entering the reproductive phase. Similarly, the finding that symmetry may fall quite early in life with onset of puberty (i.e., ages 10–15) would indicate that this period is destabilising for the maturing body, perhaps increasing susceptibility to stress at this time. Gaining more certainty about the time course of these changes is important if we are to be informed about the relationship of symmetry to structural and behavioural development as well as to lifelong stress, with implications for understanding associations of evolved indicators of fitness (13).

Nonlinear changes in symmetry across development suggest that controlling for higher-order components of age will be an important factor as symmetry research is expanded across the lifespan, especially beyond the common college age (i.e., about 18 to 22 years) pool that is mainly studied to date. These latter subjects may exhibit levels of symmetry which are not representative of effects in much younger and much older individuals.

For these reasons, we set out to replicate and extend research on links of symmetry to age across an interval from age 4 to 15 years in a large (N = 887) and relatively socially homogenous sample of children. We examined the two contrasting hypotheses which we introduced above. If symmetry is an index of the ability to respond to accumulated stressors, symmetry is predicted to decrease monotonically with age, with the youngest children being the most symmetrical. By contrast, if symmetry reflects active developmental processes generating an optimal phenotype at maturity (11), we expect increased symmetry over time; i.e., a decrease in asymmetry from age 4 to 15 years.

2 Material and Methods

2.1 Participants

Participants were visitors to the 2009 and 2010 Edinburgh International Science Festivals. In 2009, 494 children aged between 4 and 15 years (*M* = 9.4, *SD* = 2.3) participated; 208 males (age *M* = 9.5, *SD* = 2.4) and 286 females (age *M* = 9.3, *SD* = 2.3). In 2010, 402 children participated (mean age = 9.4 years, *SD* = 2.2 years, range 4 to 15); 197 males (age *M* = 9.4, *SD* = 2.2) and 205 females (age *M* = 9.5, *SD* = 2.1). Informed consent for each child to participate was gained from a parent or guardian. Participation was self-selecting and not all visitors participated. The 2009 study was granted ethical approval by the Faculty of Law, Business & Social Sciences faculty ethics committee of the University of Glasgow, and the 2010 study was granted ethical approval from the Psychology, Philosophy and Language Sciences ethics committee of the University of Edinburgh. Postcode information was collected for the 2009 festival, and a measure of deprivation derived from these suggested that participants were relatively socioeconomically homogenous and of a generally more affluent background than the general population (14).

2.2 Procedure

All data were collected by testers trained by the first author (DH) and were blind to the hypotheses. Testing took place in a dedicated laboratory section of the Festival. Both hands of each participant were scanned using a digital flatbed scanner. Motion during scanning was monitored via looking for movement artifacts in the scans: due to the relatively slow speed of the scanner (approximately 10 seconds per scan) any movement would give a blurred image. Blurred images were re-measured as appropriate though the total number of participants requiring two measurements was very low (less than 5% of total scans taken).

Hand posture was standardized with participants standing directly in front of the scanner with fingers slightly parted. This enabled easy measurement of finger widths as well as lengths. To examine the effect of posture on symmetry scores we scored 20 individuals (adults who were not part of this study) who had provided two hand scans with a different posture in each: one with fingers separated and one with fingers close together. There was no significant difference in the symmetry score according to method used ($t(38) = 0.31$, $p = 0.75$). This suggests that such differences in posture would not affect the results.

Lengths and widths of the digits (excluding the thumb) were assessed using the digital-image analysis software GIMP (GNU Image Manipulation Program, available at www.gimp.org). For lengths, digits were measured from the lower finger crease to the tip of the finger. Width was measured by drawing a line from one side of the finger to the other across the upper finger crease. Reliability of measurement was assessed in two ways. We measured two separate scans of both hands for three individuals who were not participants in this experiment. By calculating the intra-class correlation coefficient (ICC) between the paired images, we were able to evaluate the reliability of our methods. Agreement for the three pairs as measured by the first author were (ICC) .993, .989, .991, indicating high reliability. Secondly, we calculated the ICC for 25 images drawn from the sample measured twice by the first author which indicated very high reliability (ICC = .997), as expected given the high resolution of the scans. As is typical in this area of research (6, 7), symmetry was calculated using the formula $\sum|(\text{left} - \text{right}) / (\text{left} + \text{right}) / 2|$, which was then multiplied by 100. This renders each trait difference into a percentage, standardizing scores for traits of different size. Our final outcome measure was the mean of asymmetry for the eight traits (the lengths and widths of digits 2 to 5 of each hand). As individual bilateral traits may have unusually high or low symmetry compared to the body's average, mean symmetry is more representative of symmetry across the body. Usable symmetry data were available for 99.1% of subjects (888 subjects). One further subject had no recorded gender. All subsequent analyses use 887 subjects. We tested for directional asymmetry – a tendency for one side of the trait to be larger than the other and is not relevant to the asymmetry being measured here (1) – via t-tests. After controlling for multiple comparisons no traits exhibited directional asymmetry. Five traits were larger on the right side and three were larger on the left.

While there is some evidence for correlated asymmetry within an organ, based on a study of hand bones (16), typically, asymmetry scores of different soft-tissue traits, even in the same organ, such as the hand, do not correlate highly. Instead, each component provides a relatively independent assessment of developmental disturbance, from which a total estimate of developmental stability can be derived by cumulating disturbances across multiple components (15). Due to the necessity to conduct our measures both reliably, but in a brief period of time, we used only the hands. Correlations (r) between measures ranged from -.004 to .21. Controlling for multiple comparisons, only one asymmetry correlation – between the length of the fourth and the length of the third digit – was significant. To facilitate the evaluation of non-linear trends in the data, the predictor (age) was centred on the sample mean. This reduced the likelihood of multicollinearity in polynomial regression models (17).

3 Results

Participants in the 2009 and 2010 festivals did not differ significantly in age ($t(886)$, -.26, p = .79) or level of symmetry ($t(886)$, -.59, p = .56), and were therefore merged into one dataset. There were no sex differences in age ($t(886)$, .52, p = .60). Mean deviation from symmetry was .67% (SD = .23). Sex differences in mean symmetry were not significant ($t(791)$, 1.73, p = .09): male mean symmetry = .69%, SD = .25; female mean = .66%, SD = .22. We next evaluated sex differences in intra-individual variability in symmetry; that is, the consistency in symmetry score across the eight measures (the lengths and widths of digits 2 to 5). A regression model was run using the standard deviation of symmetry as the dependent variable and gender as a predictor without controlling for mean symmetry.

Gender did not significantly predict intra-individual variability in symmetry though it approached significance ($\beta = -.07$, $p = .06$).

We then examined the relationship of symmetry to age. A simple linear regression of symmetry on age indicated a significant negative association ($r = -.10$, df=886, p=.004); older children were more symmetrical. Departure from linearity was first examined descriptively by fitting a locally weighted (loess) regression of symmetry on age. The result is shown in Figure 1. Mean symmetry decreased from ages 4 to 8 years, remaining approximately flat thereafter. We then modelled this relationship using a polynomial regression of symmetry on age and gender. Terms up to and including the 4th order were included and interactions with gender were tested. Gender showed no significant main or interaction effects with age or higher powers of age, and so was dropped from the model. Backwards elimination of the polynomial terms in age resulted in a model where symmetry was expressed as a cubic function of age with coefficients: age, $\beta = .019$; age^2 $\beta = .105$; and age^3 $\beta = -.162$, $p = .011$. Overall the trend was negative, with decreasing symmetry between ages 4 to 15 years, and most of the decline in symmetry occurred between ages 4 to 8 years.

==Insert Figure 1 about here ==

4 Discussion

We identified a significant negative association between age and symmetry; children's hands became more symmetrical with increasing age, especially from age 4 to about age 8 years. This was contrary to predictions of a linear upward trend based on an error-accumulation hypothesis of symmetry loss (1). That symmetry increases, rather than decreasing or remaining stable across this period of early development, is a notable finding and is one of only two studies on the topic to our knowledge (4). Both Wilson and Manning's (1996) study and the present report noted increases in symmetry up to age 10 years. Importantly, whereas Wilson and Manning found evidence of decreasing symmetry from ages 11 to 15 years, in our data symmetry remained stable over this period. Further work is necessary to identify the cause(s) of this divergence in results.

These findings also have implications for our understanding of asymmetry across the rest of the life course. In some cases, foetuses experiencing severe developmental disorders exhibit higher levels of asymmetry, though the pattern is not universal (18). Combined with evidence that post-natal distress, but not foetal growth, is associated with higher asymmetry later in life (19), this suggests that asymmetry reflects exposure to stressors during the lifespan and that particular post-natal life phases may have especially strong and enduring effects on asymmetry. Notably, whereas asymmetry has been linked to adverse outcomes across a broad range of health-related factors in adulthood (3), effect sizes remain very variable. Failure to account for age effects in asymmetry work may partially explain large variability in effect sizes in asymmetry work in, for example, intelligence (5). If symmetry changes considerably during stressful periods during adulthood, this could confound the association between the variables of interest if age is not accounted for. Identifying whether age and asymmetry are closely related in adulthood is an important part of understanding the heterogeneous findings within asymmetry research.

The present findings may be best explained via life history research. Using a common division (21), the period from 4 to 8 years during which symmetry is enhanced is characterized as a stage in which parental care is tapered off as offspring are required to act with increasing independence as well as to interact with other children and with adults (22). During this period offspring begin to eat adult-like food, with accompanying changes in dentition, though the diet remains specialized as a consequence of the smaller size of the digestive tract (22). This childhood phase is also marked by rapid brain growth (during ages 5 to 8 years in particular), and a bodily growth spurt which, though smaller than the final growth spurt experienced during puberty, is nevertheless significant (23). This coordinated change in diet and growth, along with increased social and cognitive expectations over the period of 4 to 8 years, has led to the suggestion that this period corresponds to an ancestral hominid post-weaning phase (24). The symmetry peak at this time might be indexing novel functional enhancements underlying maturation.

Given that our study only examined children up to the juvenile stage, more data on symmetry spanning adolescence and especially the peri-pubertal period would be valuable, as this period covers the last pre-adult stage (21). Adolescents are preparing to enter the reproductive period and, if symmetry continues to index fitness related development as suggested by links with IQ in adolescents (5), an additional increment in symmetry might occur during this period.

Strengths of the present study include its sample size and the high level of socioeconomic and geographic homogeneity among the participants. The latter aspect reduces the likelihood that the result reflects confounding variables. Examining age effects on symmetry in samples where details of the socioeconomic environment are known would be valuable to assess the impact of early life factors including deprivation (13, 25).

The study has some limitations. The reliability of the symmetry scores would have been improved by acquiring multiple scans of individuals and averaging the symmetry scores across these repeated scans. Secondly, the study was cross-sectional so it remains possible that there are cohort effects with recently born children exhibiting higher symmetry than those born relatively longer ago. Following a group of children across childhood would address this issue and provide more robust confirmation of the findings.

In summary, the finding that symmetry increased across early development supports the idea that symmetry is not merely an indicator of accumulating stress, but that active symmetry-enhancing mechanisms also exist. This is compatible with data collected on symmetry in old-age, which suggest that symmetry is measuring developmental precision, with links of cognition to symmetry reflecting individual differences in symmetry-enhancing mechanisms active in early development (11). A second factor highlighted by these data is the contrast between increasing symmetry observed until at least the post-weaning phase compared to subsequent increases in symmetry, perhaps beginning at age 15. The sources of developmental improvement in symmetry should be studied in more detail as understanding any programmed de-resourcing of developmental maintenance mechanisms post-puberty may provide a resource for battling the effects of stress and illness thereafter. Our findings confirm the need to control for age in symmetry research, and show that symmetry does not decrease monotonically through the lifespan, but can be increased by active processes and that such processes are increasing symmetry at some, but not all, stages of childhood.

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Conflict of Interest

None declared.

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Figure 1: Symmetry increases nonlinearly with age

(see .bmp file)

Note: Symmetry is measured as a percentage. Age is measured in years. Line indicates trend. Shaded region indicates ± 1 SE.